



Coastal Vulnerability Assessment of Dry Tortugas National Park to Sea-Level Rise

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Dry Tortugas National Park Web pages are at <http://www.nps.gov/drto/index.htm>.

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Contents

Abstract4
Introduction4
Data Ranking5
The Dry Tortugas National Park.....5
Methodology.....6
Geologic Variables6
Physical Process Variables7
Coastal Vulnerability Index7
Results8
Discussion.....8
Conclusions8
References9
List of Figures.....10
List of Tables11

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Abstract

A coastal vulnerability index (CVI) was used to map the relative vulnerability of the coast to future sea-level rise within Dry Tortugas National Park in Florida. The CVI ranks the following in terms of their physical contribution to sea-level rise-related coastal change: geomorphology, regional coastal slope, rate of relative sea-level rise, historical shoreline change rates, mean tidal range and mean significant wave height. The rankings for each input variable were combined and an index value calculated for 1-minute grid cells covering the park. The CVI highlights those regions where the physical effects of sea-level rise might be the greatest. This approach combines the coastal system's susceptibility to change with its natural ability to adapt to changing environmental conditions, yielding a quantitative, although relative, measure of the park's natural vulnerability to the effects of sea-level rise. The CVI provides an objective technique for evaluation and long-term planning by scientists and park managers. Dry Tortugas National Park consists of relatively stable to washover-dominated portions of carbonate beach and man-made fortification. The areas within Dry Tortugas that are likely to be most vulnerable to sea-level rise are those with the highest rates of shoreline erosion and the highest wave energy.

Introduction

The National Park Service (NPS) is responsible for managing nearly 12,000 km (7,500 miles) of shoreline along oceans and lakes. In 2001, the U.S. Geological Survey (USGS), in partnership with the NPS Geologic Resources Division, began conducting hazard assessments of future sea-level change by creating maps to assist NPS in managing its valuable coastal resources. This report presents the results of a vulnerability assessment for Dry Tortugas National Park, highlighting areas that are likely to be most affected by future sea-level rise.

Global sea level has risen approximately 18 centimeters (7.1 inches) in the past century (Douglas, 1997). Climate models predict an additional rise of 48 cm (18.9 in.) by 2100 (IPCC, 2002), which is more than double the rate of rise for the 20th century. Potential coastal impacts of sea-level rise include shoreline erosion, saltwater intrusion into groundwater aquifers, inundation of wetlands and estuaries, and threats to cultural and historic resources as well as infrastructure. Predicted accelerated global sea-level rise has generated a need in coastal geology to determine the likely response of a coastline to sea-level rise. However, an accurate and quantitative approach to predicting coastal change is difficult to establish. Even the kinds of data necessary to predict shoreline response are the subject of scientific debate. A number of predictive approaches have been proposed (National Research Council, 1990 and 1995), including:

1. extrapolation of historical data (e.g., coastal erosion rates),
2. static inundation modeling,
3. application of a simple geometric model (e.g., the Bruun Rule),
4. application of a sediment dynamics/budget model, or
5. Monte Carlo (probabilistic) simulation based on parameterized physical forcing variables.

However, each of these approaches has inadequacies or can be invalid for certain applications (National Research Council, 1990). Additionally, shoreline response to sea-level change is further complicated by human modification of the natural coast such as beach nourishment projects, and engineered structures such as seawalls, revetments, groins, and jetties. Understanding how a natural or modified coast will respond to sea-level change is essential to preserving vulnerable coastal resources.

The primary challenge in predicting shoreline response to sea-level rise is quantifying the important variables that contribute to coastal evolution in a given area. In order to address the multi-faceted task of predicting sea-level rise impact, the USGS has implemented a methodology to identify areas that may be most vulnerable to future sea-level rise (see Hammar-Klose and Thieler, 2001). This technique uses different ranges of vulnerability (low to very high) to describe a coast's susceptibility to physical change as sea level rises. The vulnerability index determined here focuses on six variables that strongly influence coastal evolution:

1. Geomorphology
2. Historical shoreline change rate
3. Regional coastal slope
4. Relative sea-level change
5. Mean significant wave height
6. Mean tidal range

These variables can be divided into two groups: 1) geologic variables and 2) physical process variables. The geologic variables are geomorphology, historic shoreline change rate, and coastal slope; they account for a shoreline's relative resistance to erosion, long-term erosion/accretion trend, and its susceptibility to flooding, respectively. The physical process variables include significant wave height, tidal range, and sea-level change, all of which contribute to the inundation hazards of a particular section of coastline over time scales from hours to centuries. A relatively simple vulnerability ranking system (Table 1) allows the six variables to be incorporated into an equation that produces a coastal vulnerability index (CVI). The CVI can be used by scientists and park managers to evaluate the likelihood that physical change may occur along a shoreline as sea level continues to rise. Additionally, NPS staff will be able to incorporate information provided by this vulnerability assessment technique into general management plans

Data Ranking

Table 1 shows the six variables described in the Introduction, which include both quantitative and qualitative information. The five quantitative variables are assigned a vulnerability ranking based on their actual values, whereas the non-numerical geomorphology variable is ranked qualitatively according to the relative resistance of a given landform to erosion. Shorelines with erosion/accretion rates between -1.0 and +1.0 m/yr are ranked as being of moderate vulnerability in terms of that particular variable. Increasingly higher erosion or accretion rates are ranked as correspondingly higher or lower vulnerability. Regional coastal slopes range from very high vulnerability, <0.3 percent, to very low vulnerability at values >1.2 percent. The rate of relative sea-level change is ranked using the modern rate of eustatic rise (1.8 mm/yr) as very low vulnerability. Since this is a global or "background" rate common to all shorelines, the sea-level rise ranking reflects primarily local to regional isostatic or tectonic adjustment. Mean wave height contributions to vulnerability range from very low (<0.55 m) to very high (>1.25 m). Tidal range is ranked such that microtidal (<1 m) coasts are very high vulnerability and macrotidal (>6 m) coasts are very low vulnerability.

The Dry Tortugas National Park

The atoll-like, coral and carbonate sand islands of the Dry Tortugas lie about 110 km (~70 miles) west of Key West in Florida (Figure 1). These islands formed during the Holocene as wave processes in combination with a slow-steady rise in sea-level worked limestone and coral into mounds of carbonate sand with thicknesses ranging from 14 - 18 m (~45 - 55 ft) (Shinn et al, 1977). These islands were named Las Tortugas by Spanish explorer Ponce de Leon because of the large number of turtles inhabiting these islands. Later Dry was added to the name on nautical charts to let mariners know that there was no fresh water on the islands.

The largest brick structure in the Western Hemisphere is located on Garden Key and is nineteenth century Fort Jefferson. Construction began in 1846 as part of the US coastal fortification efforts following the War of 1812, but the fort was never completed. Fort Jefferson was used as a military prison during the Civil War, but was abandoned by the Army in 1874. In 1908 the Dry Tortugas were declared a wildlife refuge, then in 1935 Fort Jefferson National Monument was established, creating the first underwater park unit. In 1992 the area became Dry Tortugas National Park.

Hurricanes passing through the Gulf of Mexico are always reshaping the islands and leaving their mark on Fort Jefferson. During 2004 when Hurricane Charley passed over the Dry Tortugas, the landbridge connecting Bush Key to Garden Key washed over, but within a few hours the spit reformed (M. Ryan, personal communication, Oct. 29, 2004). Although storm impacts are not directly addressed in this report it is important to acknowledge their role in the dynamic evolution of the Dry Tortugas. Further the authors acknowledge that the islands of the Dry Tortugas owe their continued existence to coral reef productivity, which is vulnerable to not only expected accelerated sea-level rise, but also hurricane damage, increased water temperature, boat anchoring, coral disease, and fishing. Coral reef health and productivity is not directly addressed in this methodology.

Methodology

In order to develop a database for a park-wide assessment of coastal vulnerability, data for each of the six variables mentioned above were gathered from state and federal agencies (Table 2). The database is based on that used by Thieler and Hammar-Klose (1999) and loosely follows an earlier database developed by Gornitz and White (1992). A comparable assessment of the sensitivity of the Canadian coast to sea-level rise is presented by Shaw and others (1998). Also a report on the effects of rising seas on coral reefs in South Florida was presented by Lidz and Shinn (1991).

The database was constructed using a 1:40,000-scale shoreline for Dry Tortugas that was produced by the Florida Department of Environmental Protection. Data for each of the six variables (geomorphology, shoreline change, coastal slope, relative sea-level rise, significant wave height, and tidal range) were added to the shoreline attribute table (Figure 2). Ideally, a 1-minute (approximately 1.5 km) grid is used to divide the shoreline into units in which each variable will be defined. However, due to the configuration and size of the islands of the Dry Tortugas, a grid was not feasible. All of the islands except middle key (the smallest) were divided into two shoreline segments generally along their long axis. Next each variable in each grid cell was assigned a vulnerability value from 1-5 (1 is very low vulnerability, 5 is very high vulnerability) based on the potential magnitude of its contribution to physical changes on the coast as sea level rises (Table 1).

Geologic Variables

The **geomorphology variable** expresses the relative erodibility of different landform types (Table 1). These data were derived from USGS 1-meter resolution digital orthophotos of Dry Tortugas (Table 2). In addition, field visits were made within the park to ground-truth the geomorphologic classification. All areas of the Dry Tortugas are considered very high vulnerability with the exception of Loggerhead Key, which was classified as high vulnerability because of the presence of substantial stretches of beach rock that has helped protect the island and what remains of the Carnegie Institute Lab (Ginsburg, 1953) (Figure 3A). Fort Jefferson and the moat wall surrounding it are classified as very high vulnerability, even though the fort is 15 meters higher than anything else in the Dry Tortugas. This classification was made because the Fort is built upon carbonate sand, and the human resources required to maintain the Fort over time are less frequent than the replenishment of carbonate sand through biologic and physical processes (Figure 3A-E).

Shoreline erosion and accretion rates for Dry Tortugas were calculated using digitized shorelines from NOAA T-sheets, Nautical Charts, and USGS aerial photography (Table 2). Shoreline rates of change (m/yr) were calculated at 200 m intervals (transects) along the coast using Digital Shoreline Analysis System (DSAS) software (<http://woodshole.er.usgs.gov/project-pages/dsas/>) to derive the rate of shoreline change. The change rates for each transect within each grid cell were averaged to determine the shoreline change value used here, with positive numbers indicating accretion and negative numbers indicating erosion. Shoreline change rates on Dry Tortugas

